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Scenarios for the reduction of environmental impact in *Agaricus bisporus* production

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ABSTRACT

The aim of this study is to obtain a critical analysis of the reduction of environmental impacts in the production of the mushroom *Agaricus bisporus*. This is done through a series of proposed scenarios at each stage of the production process: mycelium production, composting and cultivation cycle. The improvement scenarios included in this research are: replacement of cereal straw by hay, as base material of compost; elimination of the pre-moistening phase of the straw; use of biofilters for composting in closed tunnels and pasteurization chambers; maximization of load capacity of compost in air-conditioned growing room; and energy optimization and use of renewable energy sources in the production process. The implementation of the successive improvement scenarios leads to a decrease of the environmental impact. The individual scenarios can be combined to obtain a reduction in all impact categories; one of the scenario combinations provides the best results, producing reductions in all the categories, from 16.25% in Global Warming to 194.63% in Terrestrial ecotoxicity, with other important reductions such as 55.28% in Marine aquatic ecotoxicity.

1. Introduction

Growing edible mushrooms has become more and more popular all over the world in the past few years; and there is a tendency to increase exponentially. Among edible mushrooms, *Agaricus bisporus* is one that stands out, vastly grown in more than 70 countries (Ma et al., 2014; Saravanan et al., 2013), thus being the most exported mushroom worldwide for decades (Foulongne-Oriol et al., 2014).

One fact that portraits this event is that the global market for mushrooms was valued at $29,427.92 million in 2013 and the button mushrooms segment contributed around 36.1% to the total mushroom market in 2013 (MarketsandMarkets, 2015).

Life-cycle analysis (LCA) is one of the most used techniques to identify the environmental impacts of a product, service or process (Lorenz, 2014) throughout its life cycle (Baumann and Tillman, 2004) governed under the ISO 14040 standard (ISO, 2006; Martínez et al., 2009).

Another useful aspect is the use of LCA as a tool for continuous environmental improvement, allowing the development of environmental simulations and the contrast of these improvement scenarios.

Numerous works have been conducted using the LCA methodology to analyze different scenarios for improvement in the field of agriculture and food (see Table 1). The studies of the scenarios analyzed propose alternatives for improving the composting process, mostly in agricultural wastes. However, in the literature consulted, works for scenario analysis of the production of *Agaricus bisporus* mushrooms have not been found. Many strategies in agriculture can be used to mitigate emissions and significantly reduce the environmental impacts.

Several studies propose the compost process as the best way of managing waste to improve the impact assessment for most impact categories considered (Antón et al., 2005; Bozorg Chenani et al.,

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Table 1
Scenarios of improvement in agricultural processes through LCA.

Authors	Field	Methodology
Antón et al. (2005)	Waste management options applied in protected horticulture	CML 2001
Bozorg Chenani et al. (2015)	Environmental impacts of the organics materials used in the construction of green roofs	CML 2001
Brock et al. (2012)	Management scenarios on the emissions of the wheat cultivation	CML 2001
Boulard et al. (2012)	Environmental comparison of the main types of tomato production	CML 2001, IMPACT 2002, EDIP 2003, CED
De Vries et al. (2015a, 2015b)	Integrated manure management to reduce environmental impact	ReCiPe
El Chami and Daccache (2015)	Scenarios for analysis sustainability of winter wheat production.	IPCC
Hasler et al. (2015)	Comparison of the environmental impact of different fertilizer types	ReCiPe
Lazzerini et al. (2014)	Scenarios for the reduction of the emissions in nursery industry (container-grown plants)	Global warming potential (GWP)
Lombardi et al. (2015)	Scenarios for the organic fraction of municipal solid waste	Eco-indicator'95
Niero et al. (2015)	Climate scenarios for Eco-efficient production of spring barley	ReCiPe, CML, etc
Saer et al., (2013)	Scenarios for composting system in food waste	TRACI 2
Steenwerth et al. (2015)	Management sceneries of GHG, energy and freshwater use in wine grape production	IPCC
Wiloso et al. (2015)	Treatment options for palm oil residues	CML 2001
Zhao et al. (2015)	Composting of sludge and woodchips	EASETECH

2015). An alternative scenario using non-yield biomass was proposed to effectively reduce the environmental impacts of the categories studied (Antón et al., 2005). The use of local materials, reducing the distance needed to transport the input materials, will reduce the environmental impacts, as the fuel consumption is greatly reduced (Bozorg Chenani et al., 2015). Additionally, proposing scenarios to reduce the main pollutants during the composting process, CH_4, N_2O and NH_3, will reduce the global environmental impact (Saer et al., 2013).

During the composting process, combining different material ratios, some environmental impact categories can be reduced, as many pollutants during the composting process are reduced or substituted, e.g. ammonia, nitrogen, phosphorus, etc. (Zhao et al., 2015).

By selecting the best management methodology, a great reduction can be achieved in the environmental impacts produced in a production process (Brock et al., 2012; De Vries et al., 2015a; De Vries et al., 2015b).

Selecting alternatives for wheat growing, with lower environmental impacts (El Chami and Daccache, 2015) and using lower nitrogen content fertilizer in the cultivation processes (Hasler et al., 2015), are considered a great way to reduce global emissions, particularly in Climate change and Eutrophication category. Additionally, using recycled water, green waste recovery for substrates (Lazzerini et al., 2014), proper cultivars with high protein content (Niero et al., 2015) and high-value co-products (Steenwerth et al., 2015) bare alternatives to reduce environmental impacts.

During agricultural process, many organic wastes are generated. As organic matter, the best way to reduce environmental impacts is reusing and recycling all organic waste generated, mainly processed in composting plants, recycling stations and biomass generation. When managing organic wastes and biomass residues, using the preferred alternative could improve environmental performances and orient toward best practices (Wiloso et al., 2015).

The aim of this study is to obtain a critical analysis of the reduction of environmental impacts in the production of the mushroom *Agaricus bisporus*. This is done through a series of proposed scenarios at each stage of the production process: mycelium production, composting and cultivation cycle. The study analyses the influence of renewable energies to reduce environmental impacts, determining how much a reduction of electricity consumption, or using clean energies, lead to a reduction in the environmental impacts. A change in the composition materials of the composting process by using less pollutant materials, e.g. hay replacing straw, is analyzed as an alternative to reduce impact categories. Improvements to reduce emissions throughout production processes by using biofilters as an alternative to reduce environmental emissions are also analyzed.

2. Methodology

2.1. Method and scope

Mushrooms are usually grown in facilities specially configured for such purposes; however, it is also possible to find it growing wild in almost every region of the planet. The production process is based in three clearly differentiated stages, which have already been described in other researches (Leiva-Lázaro et al., 2015; Leiva et al., 2015a, 2015b). These stages are: development of the mycelium, manufacturing of the culture substrate or compost, and finally the culture itself (see Fig. 1).

The mycelium is the mass of hyphae that composes the vegetative body of a mushroom. The process starts with the selection of the growth environment for the mycelium, which has physical, chemical and microbiological properties that stimulate and foster the growth of primordia (Mata and Savoie, 2013; Noble et al., 2003; Tanaka et al., 2013). Sorghum, wheat or rye seeds are used as grains in which the mycelium is inoculated. These grains must be boiled, drained and mixed with calcium carbonate and chalk to stabilize the pH and as an added source of calcium (Mata and Savoie, 2013; Noble et al., 2003; Tanaka et al., 2013). Lastly, sterilisation will eliminate any bacteria during the process. The inoculation is obtained by growing the mycelium of the mushroom primarily in the Petri dishes (Mata and Savoie, 2013; Noble et al., 2003; Tanaka et al., 2013), creating the suitable medium on the previously treated and sterilised seeds. Cultures on agar with peptone are suitable mediums for mycelium development. Suitable conditions in temperature, pH and carbon/nitrogen ratio must be established during the incubation phase for an optimal mycelium sprouting and colonisation. Finally, the commercial mycelium (known as "seed") is elaborated with the inoculation of the mycelium mushroom into the cereal grains (García-Rollan, 2007).

The manufacturing process of compost is performed in three stages. The first stage includes mixing and moistening the ingredients, followed by a period of composting with forced ventilation where temperatures are raised to 80 °C (denominated Phase I). Phase II begins with a period of pasteurization at constant temperatures around 60 °C (Straatsma et al., 2000) to reduce the ammonia content in the compost pile. During the processing, air is recirculated through the compost by a ventilator with air vents at the base of the compost pile. Most of the air is recirculated through the pile allowing adequate process control. Finally, the inoculation of Phase II compost is made, and it is then sent to culture plants (Leiva et al., 2015a).

The commercial mushroom culture facilities (Berendsen et al., 2012; Tripathy et al., 2009; Umar and Van Griensven, 1997) use Phase II compost packs, already inoculated with the mycelium